ANALYSIS FOR AN EXPERIMENT DESIGNED AS AUGMENTED LATTICE SQUARE DESIGN

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Abstract: SAS PROC GLM and SAS PROC MIXED procedures are given for analyzing data from experiments designed as augmented lattice square designs. A trend analysis using polynomial regression functions of row and column orders and interactions of these regressions. Higher ordered polynomial regressions are useable in the analysis as the number of rows and columns increase.

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Title: Analysis for an Experiment Designed as Augmented Lattice Square Design

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Importance: Augmented experiment designs are used internationally for screening the large number of new genotypes used in plant breeding programs. Any experiment design (complete block, incomplete block, row-column, or other) may be selected for the check or standard treatments replicated r times each. Then the blocks, incomplete blocks, or rows and columns are enlarged to accommodate the new treatments usually included in only one plot. The lattice square experiment design controls variation within each complete block in two directions (rows and columns). Augmented lattice square experiment designs (ALSDs) are easily constructed as described by Federer, W. T. (2000). Construction and analysis of an augmented lattice square design. Technical Report BU-1490-M, Department of Biometrics, Cornell University. ALSDs can accommodate c = 2k or 3k check or standard cultivars in r = k complete blocks and $n = k^2(k - 2)$ or $k^2(k - 3)$ new genotypes. An ALSD with k = 4 = r, c = 8, and n = 32 is used to illustrate a statistical analysis. A trend analysis using polynomial regression is used. The file name for this data set is auglsd.dat, and the data are presented below for the 64 responses.

1	1	1	33	17
1	1	2	1	9
1	1	3	2	9
1	1	4	40	23
1	2	1	37	21
1	2	2	34	18
1	2	3	3	9
1	2	4	4	9
1	3	1	5	9
1	3	2	38	22
1	3	3	35	19
1	3	4	6	9
1	4	1	7	9
1	4	2	8	19
1	4	3	39	23
1	4	4	36	20
2	1	1	33	17
2	1	2	9	8
2	1	3	10	8
2	1	4	39	25
2	2	1	40	22
2	2	2	34	18
2	2	3	11	18
2	2	4	12	18
2	3	1	13	18
2	3	2	37	23
2	3	3	35	19
2	3	4	14	17
2	4	1	15	16
2	4	2	16	21
2	4	3	38	25
2	4	4	36	20
3	1	1	33	24
3	1	2	17	17
3	1	3	18	17

```
3  1  4  38  18
3  2  1  39  22
3  2  2  34  12
3  2  3  19  17
3  2  4  20  16
3  3  1  21  17
3  3  2  40  25
3  3  3  35  15
3  3  4  22  17
3  4  1  23  17
3  4  2  24  17
3  4  3  37  15
3  4  4  36  15
4  1  1  33  28
4  1  2  25  20
4  1  3  26  20
4  1  4  37  25
4  2  1  38  29
4  2  2  34  22
4  2  3  27  26
4  2  4  28  26
4  3  1  29  16
4  3  2  39  32
4  3  3  35  25
4  3  4  30  26
4  4  1  31  16
4  4  2  32  16
4  4  3  40  25
4  4  4  36  30
```

The SAS/GLM and SAS/MIXED codes for this data set are:

```
options ls = 76;
proc iml;
  opn3= orpol(1:4,2); /* The 4 is the number of columns and 2 indicates that
  linear and quadratic polynomial regression coefficients are desired. */
  opn3[,1]= (1:4)`;
  op3 =opn3 ;    print op3; /* Print-out of coefficients. */
create opn3 from opn3[colname ={'COL' 'C1' 'C2'}]; append from opn3;
  close  opn3;run;
  opn4 =orpol(1:4,2); /* There are 4 rows and two regressions. */
  opn4[,1]=(1:4)` ;
  op4 =opn4;             print op4;
  create opn4 from opn4[colname ={'ROW' 'R1' 'R2'}]; append from opn4;
  close opn4; run;
data auglsd8;
  infile 'auglsd8.dat';
  input rep row col trt yield;
  if (trt>32) then new = 0; else new = 1;
/* This divides the 40 entries into 32 new treatments which are
considered as random effects and 8 checks which are fixed effects. */
  if (new) then trtn = 999; else trtn = trt;
data augbig;set auglsd8;
/* The regression coefficients are added to the data set. */
  idx = _n_;  run;
proc sort data = augbig;
  by COL; run;data augbig; merge augbig opn3; by COL; run;
```

```
proc sort data = augbig;
  by ROW; run; data augbig; merge augbig opn4; by ROW; run;
proc sort data = augbig; by idx; run;
proc glm   data = augbig;
  class  row col trt trtn rep;
  model yield = rep trt C1*rep R1*rep C1*R1*rep;
  lsmeans trt/out = lsmeans noprint; run;
proc sort data = lsmeans; by descending lsmean;
/* n is usually quite large and this statement arranges the fixed
effect means in descending order for viewing. */
proc print; run;
proc mixed data = augbig;
   class rep row col trt trtn;
   model yield = trtn/solution;
   random rep C1*rep R1*rep C1*R1*rep trt*new/solution;
/* These two statements obtian solutions for the various effects. */
   lsmeans trtn; make 'solutionr' out = sr noprint; run;
proc sort data = sr;
   by descending _est_;
/*The effect solutions are arranged from largest to smallest. */
proc print; run;
quit;
```

The output for the above example and the above program is presented in a modified version of the actual print-out of the output. Below are the linear and quadratic coefficients:

OP3		
1	-0.67082	0.5
2	-0.223607	-0.5
3	0.2236068	-0.5
4	0.6708204	0.5
OP4		
1	-0.67082	0.5
2	-0.223607	-0.5
3	0.2236068	-0.5
4	0.6708204	0.5

Class Level Information

Class	Levels	Values
ROW	4	1 2 3 4
COL	4	1 2 3 4
TRT	40	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
TRTN	9	33 34 35 36 37 38 39 40 999
REP	4	1 2 3 4

Number of observations in data set = 64

Dependent Variable: YIELD

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	54	2022.63549	37.45621	5.73	0.0041
Error	9	58.84888	6.53876		
Corrected Total	63	2081.48438			

R-Square	C.V.	Root MSE	YIELD Mean
0.971727	13.62652	2.55710	18.7656

Dependent Variable: YIELD

Source	DF	Type I SS	Mean Square	F Value	Pr > F
REP	3	634.92188	211.64063	32.37	0.0001
TRT	39	1284.68750	32.94071	5.04	0.0070
C1*REP	4	52.76528	13.19132	2.02	0.1755
R1*REP	4	3.38948	0.84737	0.13	0.9677
C1*R1*REP	4	46.87135	11.71784	1.79	0.2145
Source	DF	Type III SS	Mean Square	F Value	Pr > F
REP	3	240.67132	80.22377	12.27	0.0016
TRT	39	1066.10112	27.33593	4.18	0.0137
C1*REP	4	37.86878	9.46720	1.45	0.2953
R1*REP	4	23.77297	5.94324	0.91	0.4985
C1*R1*REP	4	46.87135	11.71784	1.79	0.2145

Fixed effect means:

OBS	_NAME_	TRT	LSMEAN	STDERR
1	YIELD	36	28.5625	3.98587
2	YIELD	22	27.5443	3.87268
3	YIELD	33	26.5625	3.98587
4	YIELD	30	24.3923	3.87268
5	YIELD	39	24.1171	1.67939
6	YIELD	20	23.9249	3.40407
7	YIELD	28	23.0745	3.40407
8	YIELD	40	23.0142	1.67939
9	YIELD	38	22.9711	1.67939
10	YIELD	19	22.3609	2.89414
11	YIELD	27	22.2280	2.89414
12	YIELD	18	22.0455	3.40407
13	YIELD	14	21.9964	3.87268
14	YIELD	17	21.7855	3.87268
15	YIELD	37	20.8976	1.67939
16	YIELD	35	20.5625	1.41148
17	YIELD	12	20.0757	3.40407
18	YIELD	11	19.6544	2.89414
19	YIELD	34	17.8125	1.41148
20	YIELD	25	17.2728	3.87268
21	YIELD	26	16.5147	3.40407
22	YIELD	24	15.8193	5.01784
23	YIELD	6	14.5671	3.87268
24	YIELD	1	14.3972	3.87268
25	YIELD	9	14.0444	3.87268
26	YIELD	8	13.7216	5.01784
27	YIELD	21	12.9400	5.01784
28	YIELD	16	12.6102	5.01784
29	YIELD	4	11.6749	3.40407
30	YIELD	2	11.5900	3.40407
31	YIELD	3	11.2568	2.89414
32	YIELD	10	10.5998	3.40407
33	YIELD	13	10.1342	5.01784
34	YIELD	23	8.6472	8.44815
35	YIELD	32	7.5988	5.01784
36	YIELD	29	7.0391	5.01784
37	YIELD	5	3.6367	5.01784
38	YIELD	31	3.5431	8.44815
39	YIELD	15	-0.5431	8.44815

40	YIELD	7	-3.1472	8.44815

REML Estimation Iteration History

Iteration	Evaluations	Objective	Criterion
0	1	245.77696870	
1	3	218.84012634	0.00762773
2	2	218.34805379	0.00012725
3	2	218.33482743	0.00000093
4	1	218.33472566	0.00000000

Convergence criteria met.

Covariance Parameter Estimates (REML)

Cov Parm	Estimate
REP	11.99469629
C1*REP	1.88018116
R1*REP	3.98577174
C1*R1*REP	4.69746155
NEW*TRT	5.87662721
Residual	8.41233535

Solution for Fixed Effects

Effect	TRTN	Estimate	Std Error	DF	t	Pr > |t|
INTERCEPT		15.84932467	1.85872722	3	8.53	0.0034
Effect	TRTN	Estimate	Std Error	DF	t	Pr > |t|
TRTN	33	6.02505345	1.80689098	9	3.33	0.0087
TRTN	34	1.78104271	1.61807612	9	1.10	0.2996
TRTN	35	3.51473327	1.61757976	9	2.17	0.0578
TRTN	36	4.97612515	1.80199562	9	2.76	0.0221
TRTN	37	5.08850236	1.67222656	9	3.04	0.0140
TRTN	38	7.28885283	1.67222656	9	4.36	0.0018
TRTN	39	9.63215629	1.67222656	9	5.76	0.0003
TRTN	40	8.35433917	1.67222656	9	5.00	0.0007
TRTN	999	0.00000000	.	.	.	.

Least Squares Means (*Check, fixed effect means.*)

Effect	TRTN	LSMEAN	Std Error	DF	t	Pr > |t|
TRTN	33	21.87437812	2.39139410	9	9.15	0.0001
TRTN	34	17.63036738	2.26946107	9	7.77	0.0001
TRTN	35	19.36405795	2.26934312	9	8.53	0.0001
TRTN	36	20.82544982	2.38836997	9	8.72	0.0001
TRTN	37	20.93782703	2.31267932	9	9.05	0.0001
TRTN	38	23.13817750	2.31267932	9	10.00	0.0001
TRTN	39	25.48148096	2.31267932	9	11.02	0.0001
TRTN	40	24.20366385	2.31267932	9	10.47	0.0001
TRTN	999	15.84932467	1.85872722	9	8.53	0.0001

(*Solutions for random effects arranged in descending order. To obtain the means, add the intercept value to each of the effects below.*)

OBS	_EFFECT_	REP	TRT	_EST_	_SEPRED_	_DF_	T	_PT_
1	REP	4		4.85091339	1.86295604	9	2.60	0.0286
2	R1*REP	2		2.51920549	1.33546047	9	1.89	0.0919
3	NEW*TRT		8	2.16475642	1.94313336	9	1.11	0.2941
4	NEW*TRT		27	2.01517588	1.90869357	9	1.06	0.3186
5	NEW*TRT		28	1.85527717	1.93230928	9	0.96	0.3621

6	NEW*TRT		30	1.81072275	1.93311801	9	0.94	0.3734
7	C1*R1*REP	4		1.73101272	1.85245416	9	0.93	0.3745
8	NEW*TRT		16	1.54679253	1.94313336	9	0.80	0.4465
9	NEW*TRT		22	1.54645580	1.93311801	9	0.80	0.4443
10	C1*REP	4		1.25643193	1.09118038	9	1.15	0.2792
11	NEW*TRT		24	1.25209662	1.94313336	9	0.64	0.5354
12	NEW*TRT		11	1.23086038	1.90869357	9	0.64	0.5351
13	NEW*TRT		19	1.17618212	1.90869357	9	0.62	0.5530
14	NEW*TRT		12	1.11283909	1.93230928	9	0.58	0.5788
15	NEW*TRT		18	1.01457415	1.94260482	9	0.52	0.6141
16	R1*REP	1		1.01019332	1.33546047	9	0.76	0.4687
17	NEW*TRT		23	1.00479517	1.99102006	9	0.50	0.6259
18	NEW*TRT		20	0.93494169	1.93230928	9	0.48	0.6400
19	NEW*TRT		21	0.92045869	1.93273116	9	0.48	0.6452
20	NEW*TRT		17	0.88317994	1.94374142	9	0.45	0.6603
21	NEW*TRT		13	0.83974581	1.93273116	9	0.43	0.6742
22	NEW*TRT		14	0.40203254	1.93311801	9	0.21	0.8399
23	C1*REP	2		0.34480113	1.09118038	9	0.32	0.7592
24	C1*R1*REP	1		0.28936528	1.85245416	9	0.16	0.8793
25	NEW*TRT		33	0.00000000	2.42417557	9	0.00	1.0000
26	NEW*TRT		34	0.00000000	2.42417557	9	0.00	1.0000
27	NEW*TRT		35	0.00000000	2.42417557	9	0.00	1.0000
28	NEW*TRT		36	0.00000000	2.42417557	9	0.00	1.0000
29	NEW*TRT		37	0.00000000	2.42417557	9	0.00	1.0000
30	NEW*TRT		38	0.00000000	2.42417557	9	0.00	1.0000
31	NEW*TRT		39	0.00000000	2.42417557	9	0.00	1.0000
32	NEW*TRT		40	0.00000000	2.42417557	9	0.00	1.0000
33	C1*REP	1		-0.02662262	1.09118038	9	-0.02	0.9811
34	REP	2		-0.42232220	1.86295604	9	-0.23	0.8257
35	C1*R1*REP	3		-0.46971222	1.85245416	9	-0.25	0.8055
36	NEW*TRT		25	-0.53275905	1.94374142	9	-0.27	0.7902
37	NEW*TRT		26	-0.55027490	1.94260482	9	-0.28	0.7834
38	NEW*TRT		15	-0.60995214	1.99102006	9	-0.31	0.7663
39	R1*REP	3		-0.77362810	1.33546047	9	-0.58	0.5766
40	R1*REP	4		-0.91895723	1.33546047	9	-0.69	0.5087
41	NEW*TRT		31	-1.01254232	1.99102006	9	-0.51	0.6233
42	C1*REP	3		-1.02947994	1.09118038	9	-0.94	0.3701
43	C1*R1*REP	2		-1.32767888	1.85245416	9	-0.72	0.4917
44	NEW*TRT		2	-1.38564933	1.94260482	9	-0.71	0.4937
45	NEW*TRT		29	-1.39513647	1.93273116	9	-0.72	0.4887
46	NEW*TRT		1	-1.42624812	1.94374142	9	-0.73	0.4818
47	NEW*TRT		32	-1.45720674	1.94313336	9	-0.75	0.4724
48	NEW*TRT		4	-1.56655327	1.93230928	9	-0.81	0.4384
49	NEW*TRT		3	-1.58335059	1.90869357	9	-0.83	0.4282
50	REP	3		-1.67547560	1.86295604	9	-0.90	0.3919
51	NEW*TRT		5	-1.76704354	1.93273116	9	-0.91	0.3844
52	NEW*TRT		6	-1.78805600	1.93311801	9	-0.92	0.3791
53	NEW*TRT		7	-1.91714185	1.99102006	9	-0.96	0.3608
54	NEW*TRT		9	-2.24587207	1.94374142	9	-1.16	0.2777
55	NEW*TRT		10	-2.47310037	1.94260482	9	-1.27	0.2349
56	REP	1		-2.75311559	1.86295604	9	-1.48	0.1736